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National survey on the use of chemicals in the working environment: estimated exposure events

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Abstract

***Objectives*—To obtain knowledge about the use and distribution of hazardous chemicals in Danish industry. This knowledge is used to regulate the occupational environment and prevent hazardous exposure.**

***Methods*—A national survey on the use of chemicals was carried out in 1989 in a stratified sample of 1448 Danish businesses. 13 000 different chemical products were reported. Information on components in the chemical products was obtained from the Danish product register data base (PROBAS) and by inquiries to suppliers and manufacturers. At the end of the study the composition of about 9400 of the products was known. A model was developed to estimate national numbers of chemical exposure events as a supplement to data on weights of chemicals used.**

***Results*—Data are presented for 36 chemical substances with chronic toxic effects and high estimated national numbers of exposure events for the industry groups included in the survey. Seven of the 36 substances are carcinogens, 17 are reproductive toxicants, 12 are allergens, and 18 are neurotoxicants according to listings of chronic toxicants used by the Danish authorities. The largest national number of exposure events was estimated for the industry groups manufacture of fabricated metal products, and personal services, cleaning, and hair dressing. These should have special attention in further preventive work.**

***Conclusions*—This survey on the use of chemicals is the first nationwide investigation in Denmark to delineate the use of all chemicals. The data have been used in a project to review occupational hazards in general in Danish industry. In the future, the data may be used as a basis for measuring chemical substitution, developing chemical safety, and as reference for more specific investigations and for follow up studies. Also job exposure matrices based on actual use of chemical products can be constructed.**

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Assessment of exposure to chemicals is an important component of both epidemiological studies and setting up priorities for the prevention and regulation of occupational hazards. Information on exposure can be obtained from different sources—for example, measurements of occupational air pollutants, biological monitoring, statistics on production and marketing of chemicals, and reviews and text books on occupational hazards. Measurements of occupational air pollutants and biological monitoring are not practicable for all industries and all chemicals. An alternative method for exposure assessment is based on combining a survey of the uses of chemical products with information on the ingredients of chemical products.[1 2]

To provide information on the occurrence and use of chemicals in Denmark the Ministry of the Environment and the Ministry of Labour initiated the Danish product register data base (PROBAS) in 1980.[3] This data base has registrations of hazardous products for occupational use based on mandatory notifications from manufacturers and suppliers. It has been supplemented with information from research and survey projects that include both hazardous and non-hazardous products.[3] A limitation of the PROBAS registration, however, is the lack of systematic registration of products not considered to be hazardous and the lack of detailed and specific information on the exposure (work processes, amount used, number of exposed people, etc).

In a documentation on chemicals that cause chronic health effects (carcinogens, reproductive toxicants, allergens, and neurotoxicants) initiated by the Danish Parliament[4] the state of knowledge on use, toxic effects, criteria for classification, and the need for further knowledge of these substances was reviewed. It was concluded that further knowledge on the use of and exposure to these chemicals in the Danish working environment was needed and our study was started to obtain such knowledge. Thus the aim of the study was to provide a basic knowledge on the use of and exposure to chemicals in Danish industry with a focus on the chronic toxicants. The study was intended to be the basis for regulatory and voluntary substitution of carcinogens, reproductive toxicants, allergens, and neurotoxicants.

As a supplement to information on the total weight of chemicals used the number of people reported to handle or use the chemicals

was used in our study to describe the general picture of industrial chemical use in Denmark. To our knowledge, this strategy has not been used before.

Our investigation of a stratified sample of Danish businesses was the first nationwide study of this kind. This paper focuses on potential occupational exposure and presents extrapolated results for selected carcinogens,[5] reproductive toxicants,[6] allergens,[7-10] and neurotoxicants,[11] defined by listings of chronic toxicants from the Danish authorities or from Scandinavian lists. Other data studied will be published elsewhere.

Methods

In the first phase of the investigation, initiated in 1989, data collection was carried out in a stratified sample of 1448 Danish businesses grouped into 19 industrial groups, and four size groups according to the number of employees (unknown, 1–9, 10–99, and $\geqslant 100$). The national framework for the survey included about 73 000 businesses and 950 000 employees. The businesses were asked to complete postal questionnaires of the annual use of chemical products and information about each product on product category (paint, glue, etc), work process (painting, gluing, etc), and the number of people handling or using the products in each process.[12] In the second phase of data collection, the chemical products reported were identified, and information on components for the products was obtained from PROBAS[3] and by inquiries to suppliers and manufacturers.[13] All data received before July 1992 were included.

Chemical products were defined as solid, liquid, or gaseous substances or mixtures of substances. Products were included in this survey when used as: raw materials or semi-synthetics in the manufacturing industries; materials for repair, impregnation, or other treatment of machinery, equipment, buildings etc; cleaning agents, disinfectants, or pesticides; materials in administration—for example, photocopy toner.

Chemical substances were defined as chemicals or pure substances identified by a CAS RN (chemical abstract service registry number).

Nineteen *industry groups* were defined that covered industrial areas with an expected comparable use of chemicals. The appendix lists the type of business and international standard industrial classification (ISIC) codes[14] included in each industry group. Industries or businesses with expected low use of chemicals were excluded—that is, several of the subgroups in the wholesale and retail trade; finance, insurance, real estate, and business services; transport, storage, and communication; public administration and defence; recreational and cultural services; teaching; and international and other extra-territorial bodies. Manufacture of food and drink and restaurants and hotels were excluded as the most important chemical products associated with these businesses were considered to be cleaning agents that had been surveyed in an earlier investigation.[15]

To obtain a measure of the number of events that involved possible exposure to the chemicals in question the number of *exposure events* was defined as the number of products used multiplied by the number of people reported to handle or use the products—that is, one exposure event was defined as one person handling or using one product containing the substance in question. Hence the number of exposure events is a measure of the spread of a chemical.

EXTRAPOLATION MODEL

The national estimates of the number of exposure events and the national estimates of weights used annually were extrapolated by means of a model based on the assumption that the number of exposure events that involved a chemical substance and the weight of chemical used are proportional to the size of the business measured by the number of employees. In homogenous groups of businesses the total number of exposure events and the total chemical weights were calculated for each substance by the formulas:

$$E = e\,A/a \quad \text{or} \quad E = e\,B/b$$
$$M = m\,A/a \quad \text{or} \quad M = m\,B/b$$

where:

E = total number of exposure events for the chemical for all work sites in the size group within the study framework
M = total weight of the chemical for all work sites in the size group within the study framework
e = number of exposure events for the specific substance among the sample respondents within that size group
m = weight of chemical used or handled by sample respondents within that size group
A = number of employees in all work sites in the size group within the study framework
a = number of employees in the sample respondent work sites within that size group
B = number of work sites within the study framework
b = number of respondent work sites
the figures B and b are chosen for work sites from which information about size was missing.

A calculation of m was made with the following formulas:

$$m = \sum_{i=1}^{n} k_i\,p_i \quad \text{and} \quad p_i = \sum_{h=1}^{n} p_{i,h}$$

where: k_i = concentration of substance in product number i
p_i = total weight of the product number i used by businesses within that size group
h = work site number "h" within that size group.

The national weight of a substance used or handled in a group of businesses was calculated as the sum of all Ms within all the size groups. The national number of exposure events in an industry group was calculated as the sum of all Es within all the size groups.

ESTIMATION ON SELECTED CHEMICALS

The survey covered in principle all chemical substances registered in the identified products. In accordance with the aims of the study the extrapolated national results for the industry groups included in the survey are presented for carcinogens (C),[5] reproductive toxicants (R),[6] allergens (A),[7-10] and neurotoxicants (N)[11] as defined from lists of substances with chronic toxic effects used by the Danish authorities or from Scandinavian lists (CRAN substances). Results are presented for substances with chronic toxic effects and with a total of 25 000 or more estimated exposure events.

Estimated numbers of exposure events, estimated annual weights used, and numbers of registered products containing the substances were limited to the reported products, for which component information was obtained. All data presented in the text and tables are extrapolated into national figures for the industries included in the survey. All results shown are based on substances defined by CAS RN. In case of discrepancies between the chemical name and the CAS RN, the CAS RN is taken to be the true identification of the substance. This is included in the tables and shown in parentheses when a substance is mentioned in the text for the first time. For white spirit a special CAS RN was constructed for use in PROBAS only (beginning with 99999 . . .) that represents white spirit not further specified.

Results

Answers were received from 1010 of the 1448 businesses (70%; 438 non-responders). Of these, 894 used chemicals and had employees. About 13 000 different chemical products were reported. When the second data collection was closed in July 1992, chemical composition was identified for about 9400 products (73%) containing about 4800 different substances. Information on the chemical composition was not available for the remaining 3600 products in July 1992. For the individual industry groups, information on the component substances was obtained for 66%–95% of the products. The annual weights used were reported for 88% of the total number of different products. About 4350 products were registered to contain CRAN substances. Reproductive toxicants occurred in 29% of the products, neurotoxicants in 27%, allergens in 21%, and carcinogens in 16%.

Table 1 Estimated numbers (≥25 000) of exposure events for substances in 19 industry groups

CAS RN	Substances	CRAN categories for substances*	Manufacture of basic metals	Manufacture of fabricated metal products	Electrical machinery and apparatus	Manufacture of transport equipment	Painters and carpenters	Construction
	Industry group number		011	012	013	014	021	022
71-43-2	Benzene	CR N	230	16 000	670	3200	250	5100
108-46-3	1,3-Benzenediol	N	10	570	80	—	1300	16
1675-54-3	Bisphenol A diglycidylether	A	40	15 000	1500	440	1500	4800
1303-96-4	Borax	R	31	3700	95	6900	—	2000
78-93-3	Butanone	R N	300	12 000	820	360	880	670
111-76-2	Butoxyethanol	N	—	20 000	1500	1900	290	5800
141-32-2	Butyl acrylate	A	—	6500	76	110	5900	4800
26172-55-4	5-Chloro-2-methyl-3-isothiazolone	A	—	48 000	8000	13 000	3600	14 000
108-94-1	Cyclohexanone	N	10	3900	810	230	—	1200
75-71-8	Dichlorodifluoromethane	N	190	7900	1000	430	1700	4400
75-09-2	Dichloromethane	CR N	660	3100	460	340	2100	5700
60-00-4	EDTA	R	130	4100	100	3700	2700	1900
139-33-3	EDTA, disodium salt	R	—	12 000	2600	12 000	—	3100
64-02-8	EDTA, tetrasodium salt	R	280	10 000	840	1500	2700	4700
106-89-8	Epichlorohydrin	CRAN	40	17 000	2100	260	1500	5000
141-43-5	Ethanolamine	N	260	10 500	1900	3000	290	4500
64-17-5	Ethyl alcohol	R	120	20 000	3100	2400	6000	9800
75-21-8	Ethylene oxide	CR N	150	2000	170	330	15	3300
50-00-0	Formaldehyde	C A	120	20 000	1200	910	18 000	4800
123-31-9	Hydroquinone	RA	—	900	460	190	—	850
98-82-8	Isopropylbenzene	N	—	11 000	180	210	760	1200
108-31-6	Maleic acid anhydride	A	20	19 000	430	400	2100	2300
80-62-6	Methyl methacrylate	RA	210	12 000	260	1600	1800	2800
95-70-5	2-Methyl-1,4-benzendiamine	A	—	—	—	—	—	—
101-68-8	Methylenebisphenylene diisocyanate	A	77	1500	290	1300	7000	7800
2682-20-4	2-Methyl-3-isothiazolone	A	—	48 000	8000	13 000	3600	14 000
108-95-2	Phenol	N	180	8200	1400	700	440	4300
14808-60-7	Quartz (SiO_2)	C	130	7400	50	260	—	12 000
7631-86-9	Silica (unspecified)	C	1400	47 000	3800	2500	10 000	18 000
64742-88-7	Solvent naphtha (petroleum), medium aliphatic	RN	20	22 000	78	430	100	3600
100-42-5	Styrene	RN	110	22 000	1000	770	4800	4600
108-88-3	Toluene	RN	420	64 000	1500	2700	15 000	5400
71-55-6	1,1,1-Trichloroethane	N	880	7000	3000	2600	4500	2400
102-71-6	Triethanolamine	A	710	21 000	1000	7400	2100	14 000
999999-95-0	White spirit	RN	170	27 000	1400	3900	35 000	12 000
1330-20-7	Xylenes	RN	790	97 000	4400	3500	16 000	15 000
	Total		7700	650 000	54 000	92 000	150 000	210 000

*C = carcinogenic; R = reproductivity toxicity; A = allergenic; N = neurotoxic.

The total estimates of the number of exposure events were above or equal to 25 000 for a total of 36 substances (table 1). Among these substances seven (19%) were carcinogens, 17 (47%) were reproductive toxicants, 12 (33%) were allergens, and 18 (50%) were neurotoxicants. For this selected group of substances two additional exposure measures were evaluated: estimated national weights of each substance used in each industry group (table 2) and number of different products containing each chemical substance.*

ESTIMATED NUMBERS OF EXPOSURE EVENTS

The highest national estimates of the number of exposure events were found in manufacture of fabricated metal products and personal services, cleaning, and hair dressing. All but one of the 36 substances were used in more than half of the industry groups that were included (table 1). 2-Methyl-1,4-benzendiamine (95-70-5) was found in one industry group only, the personal services, cleaning, and hair dressing group, where it is used as a pigment in hair colour preparations. The high estimate of the number of exposure events for this substance may represent a methodological problem originating from the separate registration in PROBAS of nearly identical products, such as hair colour preparations with different shades. The estimated weight of this substance was 44 kg.

The highest national estimates of the number of exposure events for any of the industry groups were obtained for a preservative, the active ingredients in Kathon CG (5-chloro-2-methyl-3-isothiazolone (26172–55–4) (260 000) and 2-methyl-3-isothiazolone (2682–20–4) (250 000)) occurring mainly in personal services, cleaning, and hair dressing and in manufacture of fabricated metal products, and for xylenes (1330–20–7) (220 000) occurring mainly in manufacture of fabricated metal products, and in agriculture, hunting, and forestry; followed by ethyl alcohol (64–17–5) (180 000) occurring mainly in personal services, cleaning, and hair dressing, and in health services and pharmacies; silica (unspecified) (7631–86–9) (180 000) occurring mainly in manufacture of fabricated metal products and in personal services, cleaning, and hair dressing; and ethanolamine (141–43–5) (160 000) occurring mainly in personal services, cleaning, and hair dressing.

*A table on number of different products containing each substance is available from the authors.

Publishing and printing	*Wholesale trade (selected industries)*	*Manufacture of textiles and leather*	*Manufacture of wood and furniture*	*Manufacture of chemicals*	*Manufacture of paints, petroleum, and bitumen products*	*Manufacture of non-metallic mineral products*	*Manufacture of precision and optical intruments*	*Manufacture of plastic and boat building and repair*	*Personal services, cleaning, and hair dressing*	*Sewage and refuse disposal*	*Agriculture, hunting, and forestry*	*Health services and pharmacies*	*Total*
031	**041**	**051**	**052**	**053**	**054**	**055**	**056**	**057**	**081**	**082**	**101**	**111**	
2100	3900	430	1400	1400	210	3100	46	36	140	30	1700	560	41 000
260	—	—	—	39	—	140	—	—	94 000	—	—	54	96 000
770	950	380	510	—	—	1600	2300	150	—	—	—	96	30 000
1000	560	98	560	490	—	150	69	21	540	240	5200	3100	25 000
4100	1200	1300	1600	270	—	680	330	710	260	28	1500	300	27 000
5100	6000	3800	1500	290	1050	690	78	1500	3100	420	740	1300	55 000
320	170	12	970	—	1100	100	29	—	10 000	—	1300	930	32 000
20 000	24 000	7100	20 000	300	460	17 000	52	5400	52 000	940	670	24 000	260 000
1300	260	4200	280	360	210	36	850	520	—	—	13 000	24	27 000
360	1100	1300	3000	—	—	410	6	1000	4000	—	540	1400	29 000
360	1900	380	110	8300	260	510	650	530	—	—	2	1200	27 000
1800	1400	1800	240	91	—	3000	29	1900	21 000	39	1500	7400	53 000
760	4900	820	4700	—	—	220	23	1500	—	—	4	2200	45 000
9800	14 000	6400	2100	1700	210	5900	1500	580	44 000	850	120	36 000	140 000
610	1400	450	510	—	38	2100	1800	150	—	—	—	44	33 000
1050	4700	820	2300	7100	19	140	—	950	110 000	—	2200	8800	160 000
14 000	7900	4900	7400	18 000	940	5800	6500	730	31 000	130	1400	38 000	180 000
480	940	1700	280	450	—	400	170	760	21 000	—	1100	11 000	44 000
7600	2000	1700	4800	8100	400	11 000	58	690	30 000	120	8800	11 000	130 000
9700	140	—	120	13	—	190	2200	110	32 000	—	7	5700	53 000
2000	1100	60	820	200	930	570	6	120	10 000	4	2100	2100	33 000
880	860	650	660	250	530	150	69	780	—	—	—	76	29 000
930	1100	730	270	13	1300	460	2200	53	10 000	20	1300	5800	43 000
—	—	—	—	—	—	—	—	—	94 000	—	—	—	94 000
2300	1800	30	62	—	—	950	580	1200	—	—	—	320	25 000
17 000	24 000	7100	20 000	300	460	17 000	29	4600	52 000	940	670	24 000	250 000
1200	840	2600	670	580	—	1300	1300	840	260	210	550	1200	27 000
360	270	380	400	6900	610	1400	110	170	10 000	—	—	210	41 000
12 000	13 000	1900	6100	1100	4700	10 000	6300	550	20 000	290	4700	13 000	180 000
1300	1900	440	480	38	290	1200	260	780	79	20	1300	140	34 000
1400	3700	30	150	120	950	640	160	540	800	120	60	4800	47 000
6300	5000	4400	5900	8700	1400	2300	2500	1100	—	99	11 000	2600	140 000
10 000	5300	1800	1900	8200	260	1600	170	1400	250	200	—	3500	55 000
3300	1500	820	590	330	210	2100	1300	710	460	260	5300	5100	68 000
2700	5600	410	6000	740	5700	5100	770	700	20	98	8200	3100	120 000
7400	11 000	3000	9300	870	3500	4100	2800	1300	—	260	39 000	2600	220 000
150 000	150 000	62 000	110 000	75 000	26 000	100 000	35 000	32 000	650 000	5300	110 000	220 000	2900 000

Table 2 Estimated weights used (tonnes) of substances with a total of ≥25 000 exposure events in 19 industry groups

CAS RN	Substances	CRAN categories for substances*	Manufacture of basic metals	Manufacture of fabricated metal products	Electrical machinery and apparatus	Manufacturer of transport equipment	Painters and carpenters	Construction	Publishing and printing	Wholesale trade (selected industries)
	Industry group number		011	012	013	014	021	022	031	041
71-43-2	Benzene	CRN	0·21	3·2	0·045	4·2	< 0·0001	6·4	0·17	0·059
108-46-3	1,3-Benzenediol	N	0·0086	0·061	0·033	—	0·1	0·001	0·011	0·0077
1675-54-3	Bisphenol A diglycidylether	A	0·017	170	9·1	1·2	0·077	21	0·091	0·87
1303-96-4	Borax	R	0·32	1·9	0·078	0·65	—	1·5	1·3	0·58
78-93-3	Butanone	RN	0·58	25	3·1	6600	0·75	2·7	290	1·2
111-76-2	Butoxyethanol	N	—	350	1·4	45	4·1	1·8	6·9	30
141-32-2	Butyl acrylate	A	—	0·42	0·0084	0·57	0·17	0·13	0·0041	0·0005
26172-55-4	5-Chloro-2-methyl-3-isothiazolone	A	< 0·0001	0·034	0·0041	0·0001	0·002	0·0001	0·013	0·0018
108-94-1	Cyclohexanone	N	0·0012	9·3	1	0·32	0·075	0·16	6	0·096
75-71-8	Dichlorodifluoromethane	N	0·09	490	0·31	4·2	2	7·1	0·16	5·1
75-09-2	Dichloromethane	CRN	1·1	160	110	21	1·8	30	0·45	2
60-00-4	EDTA	R	0·0077	0·47	0·19	0·5	0·42	0·095	0·24	0·14
139-33-3	EDTA, disodium salt	R	—	2·1	3·6	0·27	—	0·089	2·1	0·105
64-02-8	EDTA, tetrasodium salt	R	0·004	20	0·19	3·4	0·53	0·15	2·3	10
106-89-8	Epichlorohydrin	CRAN	< 0·0001	0·026	0·0016	0·0001	< 0·0001	0·0002	< 0·0001	0·0001
141-43-5	Ethanolamine	N	0·028	20	11	2	0·54	0·18	9·7	1·1
64-17-5	Ethyl alcohol	R	2·7	510	80	6800	240	110	1500	120
75-21-8	Ethylene oxide	CRN	< 0·0001	10	0·0011	0·019	< 0·0001	0·07	< 0·0001	0·0006
50-00-0	Formaldehyde	CA	0·52	150	4·1	2·5	2·6	0·23	1·9	2·4
123-31-9	Hydroquinone	RA	—	0·32	0·79	11	—	0·0008	53	0·0011
98-82-8	Isopropylbenzene	N	—	13	0·19	0·053	0·074	0·14	0·69	0·14
108-31-6	Maleic acid anhydride	A	0·0001	4·8	31	0·026	0·0001	0·033	< 0·0001	0·025
80-62-6	Methyl methacrylate	RA	0·0048	730	0·0084	0·26	0·14	0·47	0·025	0·0007
95-70-5	2-Methyl-1,4-benzendiamine	A	—	—	—	—	—	—	—	—
101-68-8	Methylenebisphenylene diisocyanate	A	18	16 000	3	60	4	67	83	2·1
2682-20-4	2-Methyl-3-isothiazolone	A	< 0·0001	0·014	0·0016	0·0001	0·002	0·0001	0·012	0·0018
108-95-2	Phenol	N	1·7	27	0·0012	40	0·021	11	0·009	16
14808-60-7	Quartz (SiO_2)	C	3500	300	4·2	16	—	42 000	0·16	0·52
7631-86-9	Silica (unspecified)	C	9·9	300	26	24	2	100	3·4	120
64742-88-7	Solvent naphtha (petroleum), medium aliphatic	RN	0·0026	220	0·8	5·6	0·026	170	17	61
100-42-5	Styrene	RN	0·017	34	110	660	0·0067	1800	0·0073	0·29
108-88-3	Toluene	RN	0·59	360	3·9	18 000	21	39	6300	110
71-55-6	1,1,1-Trichloroethane	N	2·6	620	180	13	2	13	7·3	0·62
102-71-6	Triethanolamine	A	0·12	35	0·38	1·2	1	8·3	1·1	0·3
999999-95-0	White spirit	RN	3·2	170	7·4	25	120	220	12	31
1330-20-7	Xylenes	RN	1·5	5600	260	1900	20	85	7	360
	Total		3500	26 000	850	34 000	420	45 000	8300	880

*C = carcinogenic; R = reproductivity toxicity; A = allergenic; N = neurotoxic.

ESTIMATED WEIGHTS

The estimated weights for the selected substances varied from a total of less than 50 kg to more than 200 000 tonnes (table 2). High weight chemicals were silica (unspecified)* with 219 000 tonnes occurring mainly in manufacture of non-metallic mineral products, and quartz (SiO_2) (14808–60–7) with 49 000 tonnes occurring mainly in construction. Solvents represented a total of about 100 000 tonnes, and typical high weight solvents were white spirit (999999–95–0) with 40 000 tonnes occurring in manufacture of paints, petroleum, and bitumen products; toluene (108–88–3) with 26 000 tonnes occurring in manufacture of transport equipment and in publishing and printing; xylenes with 16 000 tonnes occurring in manufacture of paints, petroleum, and bitumen products, and in manufacture of fabricated metal products; ethyl alcohol with 13 000 tonnes occurring in manufacture of transport equipment; butanone (78–93–3) with 6900 tonnes occurring in manufacture of transport equipment; methylenebisphenylene diisocyanate (MDI) (101–68–8) with 26 000 tonnes occurring in manufacture of fabricated metal products and in manufacture of plastic and boat building and repair.

In the whole data set, disregarding the number of exposure events, high weights (>1000 tonnes) were estimated for 25 of the substances. For 11 of these, the estimated national number of total exposure events was less than 25 000.

In our paper table 2 presents estimated weights of substances with 25 000 or more exposure events. The annual weights of use of chronic toxic chemicals are published in full length tables in a Danish report.[13]

For the carcinogens the highest estimated weights were found in manufacture of non-metallic mineral products, construction, and manufacture of plastic and boat building and repair, but the highest estimated numbers of exposure events were found in manufacture of fabricated metal products, personal services, cleaning, and hair dressing, and construction.

*Many registrations of products containing silica included crystalline and amorphous silica, as well as sand. Hence estimated weight will include non-carcinogenic silica, and consequently be much too high in this paper.

Manufacture of textiles and leather	Manufacture of wood and furniture	Manufacture of chemicals	Manufacture of paints, petroleum, and bitumen products	Manufacture of non-metallic mineral products	Manufacture of precision and optical instruments	Manufacture of plastic and boat building and repair	Personal services, cleaning, and hair dressing	Sewage and refuse disposal	Agriculture, hunting, and forestry	Health services and pharmacies	Total
051	052	053	054	055	056	057	081	082	101	111	
0·0002	0·015	0·21	0·012	5·4	0·0034	0·0004	0·0007	0·0003	0·007	0·12	20
—	—	0·035	—	0·0084	—	—	0·017	—	—	0·0065	0·29
0·02	7·3	—	—	8·9	19	0·63	—	—	—	0·002	240
2·4	0·1	170	—	0·13	0·29	0·018	0·12	0·046	33	0·028	210
1·1	32	0·13	—	5·8	1·3	3·4	< 0·0001	0·0035	0·026	0·2	6900
18	66	210	6·2	1·5	0·061	0·76	0·48	0·094	0·063	13	750
0·0001	0·0033	0·019	7·5	0·0002	0·0003	—	0·0037	—	0·012	0·0025	8·8
0·04	1·5	0·43	0·0013	0·0001	0·0005	0·048	0·0027	< 0·0001	0·0006	0·0004	2
0·16	0·12	4·1	0·038	0·074	0·6	0·28	—	—	44	0·0005	66
0·17	1	—	—	0·12	0·073	5·8	0·062	—	4·6	0·35	520
0·006	6·9	55	86	43	19	1200	—	—	0·005	0·66	1700
0·066	0·13	380	—	0·081	0·0051	0·57	3·5	0·12	0·21	0·65	390
0·0025	0·042	—	—	0·75	0·0001	0·01	0·001	—	0·001	0·0085	9·1
36	100	2600	0·12	1·9	0·051	0·96	33	0·19	0·015	39	2900
< 0·0001	0·0007	—	0·011	0·0024	0·0044	< 0·0001	—	—	—	—	0·047
47	0·091	170	0·1	0·0075	—	0·047	20	—	1	0·76	280
6·9	650	1300	990	81	46	24	64	0·93	4·5	210	13 000
0·0083	< 0·0001	0·0042	—	0·0032	< 0·0001	12	0·0001	—	0·0002	< 0·0001	23
4·6	30	4·9	0·077	4300	0·0001	0·1	0·1	0·0018	0·62	5·9	4500
—	< 0·0001	0·0023	—	< 0·0001	0·6	1·3	0·0024	—	0·0003	3·3	71
0·0001	0·29	4·1	17	0·12	< 0·0001	0·047	—	< 0·0001	0·68	0·0002	36
0·0008	0·14	0·0004	34	0·0056	< 0·0001	0·26	—	—	—	< 0·0001	71
0·026	0·031	< 0·0001	12	0·0017	0·0045	0·026	0·0037	0·01	0·012	16	760
—	—	—	—	—	—	—	0·044	—	—	—	0·044
—	1·4	—	—	240	130	9700	—	—	—	0·36	26 000
0·038	0·55	0·16	0·0005	< 0·0001	0·0005	0·0014	0·001	< 0·0001	0·0006	0·0002	0·78
1	1·2	0·85	—	4100	0·0023	< 0·0001	0·0002	0·0009	0·65	0·25	4100
0·009	0·038	0·38	3·7	2700	0·01	1·6	0·32	—	0·13	6·4	49 000
6·3	180	120	1200	216 000	26	36	0·012	0·22	5·6	3·1	219 000
0·86	3·1	0·0001	0·47	5	0·5	0·37	2·2	0·057	6·1	0·068	490
0·052	0·064	1·4	1·3	0·28	16	38	0·0056	0·033	—	0·0035	2700
15	420	170	420	17	19	0·62	0·068	0·076	0·84	4·1	26 000
1·1	97	2	0·53	55	2·3	700	7	0·057	—	1·05	1700
0·44	0·16	530	0·91	68	0·12	110	0·21	0·11	0·74	0·99	760
140	5300	730	32 000	81	3·8	17	5	8·9	28	1200	40 000
14	920	11	6600	44	4·8	140	0·025	6·1	190	5·3	16 000
300	7800	6500	41 000	228 000	290	12 000	140	17	320	1500	—

For the reproductive toxicants the highest estimated weights were found in manufacture of paints, petroleum, and bitumen products, transport equipment, and fabricated metal products, and publishing and printing, but the highest estimated numbers of exposure events were found in manufacture of fabricated metal products, personal services, cleaning, and hair dressing, and health services and pharmacies.

For the allergens the highest estimated weights were found in manufacture of fabricated metal products, and manufacture of plastic and boat building and repair, but the highest estimated numbers of exposure events were found in manufacture of fabricated metal products, and personal services, cleaning, and hair dressing.

For the neurotoxicants the highest estimated weights were found in manufacture of paints, petroleum, and bitumen products, manufacture of transport equipment, and manufacture of fabricated metal products, but the highest estimated numbers of exposure events were found in manufacture of fabricated metal products, and personal services, cleaning, and hair dressing.

NUMBERS OF DIFFERENT PRODUCTS REGISTERED

The numbers of different products registered for the 36 substances (with a total of 25 000 or more estimated exposure events) were between 27 and 775. The substances with the highest estimated numbers of different products registered were xylenes (775 products) occurring mainly in manufacture of fabricated metal products, in electrical machinery and apparatus, and in construction; silica (unspecified) (594 products) occurring mainly in manufacture of fabricated metal products and in electrical machinery and apparatus; ethyl alcohol (491 products) occurring mainly in publishing and printing, in manufacture of fabricated metal products, and in health services and pharmacies; toluene (473 products) occurring mainly in manufacture of fabricated metal products and in electrical machinery and apparatus; white spirit (414 products) occurring mainly in manufacture of fabricated metal products; and formaldehyde (50–00–0) (372 products) occurring mainly in manufacture of fabricated metal products.

In the whole data set, disregarding the number of exposure events, a total of 28

substances were registered in more than 100 different products. For three of these the estimated number of exposure events was less than 25 000.

Discussion

High numbers of exposure events in the industry groups included were estimated for some preservatives, solvents, and unspecified silica. Not all chemicals with many estimated exposure events were high weight chemicals, and several high weight chemicals did not have high estimated numbers of exposure events. Industries that merit special attention as assessed by the estimated national number of exposure events were manufacture of fabricated metal products, and personal services, cleaning, and hair dressing.

The validity of the national estimates of the number of exposure events and of the annual use (weights) of chemicals is dependent on the representativeness of the businesses that were included in the sample and on their response to the questionnaire. The validity of the response information was controlled in the coding and registration phase of the survey, and considered good. Businesses answered according to instructions or consultations, and telephone questionnaires were used to specify ambiguous answers, along with random work environment service inspections of work sites (no statistical validity control was performed). As the representative nature and the proportion of products with information on composition varied between the 19 industry groups, the data for some industry groups should be considered more valid than for others. For the total investigation answers were obtained for 70% of the 1448 businesses, information on composition were obtained for 73% of the products, and information on weights for 88%. The industry groups with the highest national estimates of the number of exposure events (manufacture of fabricated metal products, personal services, cleaning, and hair dressing, and health services and pharmacies) had response rates from the businesses of 74%, 83%, and 83% respectively, information on composition of the products of 76%, 84%, and 78% respectively, and information on weights of 88%, 92%, and 90% respectively. Therefore, the validity of these data seems satisfactory.

From data to be published it seems that each industry group has its own characteristic set of work processes comprising the major use of chemicals. For each industry group the reported work processes were concentrated on six to eight processes out of the 20–50 defined for each industry group, which supports the assumption of homogeneity within each group.

Manufacture of fabricated metal products had the highest estimates of the number of exposure events for 18 of the 36 substances and the highest numbers of registered products for 27 of the 36 substances. This industry group also has the highest number of employees. It is suggested that the high estimated number of exposure events is due to the use of many different metal working and cutting fluids, degreasing agents, paints, metal coatings, etc that contain many different toxic substances. Especially, metal working and cutting fluids are more often registered in the present investigation than in a previous study.[16]

Another industry group with a very high national estimate of the number of exposure events was personal services, cleaning, and hair dressing although it has fewer employees. A few substances (1,3-benzendiol (108-46-3) and ethanolamine) were used in many different products within this industry group, which again contributes to the high estimate of the number of exposure events. Health services and pharmacies and construction also showed high national estimates of the number of exposure events in agreement with their high number of employees.

Manufacture of fabricated metal products and manufacture of chemicals had the highest national loads of chemicals—based on the estimated total weights of the chronic toxic substances included. Users of silica (unspecified) as sand had the highest weights of use—for example, manufacture of non-metallic mineral products that used 216 000 tonnes of silica. Industries with medium weights were manufacture of paints, petroleum, and bitumen products with an estimated weight of 32 000 tonnes of white spirit, and manufacture of transport equipment with 18 000 tonnes of toluene.

Previous publications on registered chemicals have ranked chemicals by the number of different products containing the substances.[16 17] In our presentation, the main criterion for ranking was the estimated number of exposure events. For the selected substances the estimated weights used and the number of different products registered were evaluated. Xylenes, silica, toluene, and ethyl alcohol were high on all three exposure measures. Within industry groups this tendency was less pronounced although manufacture of fabricated metal products was high both for substances with a high number of registered products and for a high estimated number of exposure events.

A questionnaire based survey of the working conditions of employees in Denmark was conducted in 1990.[18] The exposure to chemicals reported by the employees agreed with the results of our survey: exposure to chemical products was considered a major problem in cleaning, social and health services (cleaning agents), and in the construction and the wood and furniture industry (solvents).[19]

In contrast with trade statistics on chemicals, our study includes substances that occur as components in the products—for example, solvents as part of paints, which will be missing when the import of pure substances (raw materials) and of the formulated products are registered. Hence, the national weights for the industry groups included in this study will be higher and more valid than trade statistics. To illustrate this the annual use of white spirit amounted to 19 400 tonnes according to

trade statistics and 40 000 tonnes in this study of selected industry groups from the same year.[20 21] Also, this study includes information on the industrial areas of use.

A Danish investigation of a stratified random sample of businesses in the wood and furniture industry included a survey of the use of chemical products. In this survey 673 different chemical products were found in 200 businesses.[22] In our investigation 645 different chemical products were registered in the wood and furniture industry group, but the data were collected from fewer businesses. Most of the frequently registered substances in our investigation were included among the 20 most frequent substances in the earlier survey, which implies that a representative sample had been drawn in this industry group.

For carcinogens, the estimated weights used may be compared with a registration based on mandatory notifications from Danish manufacturers and importers.[23] Comparisons for about 40 selected carcinogens showed that the annual use was lower in our study for 80% of these substances. Twenty per cent were more than 100 times lower. Some of the industrial areas excluded in our investigation may have contributed in the notification of carcinogens—for example, public and private transportation, manufacture of food and drink, etc. The comparison was difficult because the notification data did not specify industry groups for all chemicals. According to the notification of carcinogens,[23] 127 of 240 carcinogens (53%) listed in 1989 were used in Denmark, and for our investigation 73 of 284 carcinogens (26%) listed in 1992 were found in the reported products. This discrepancy may be due both to the excluded industrial areas and to the fact that information on components was missing for a quarter of the products in our investigation.

Occurrence of contact allergens has mainly been investigated with a focus on product categories.[16] A comparison shows that among the 10 most often registered contact allergens in an investigation made in 1990, five were among the most frequent allergens in the present investigation—for example, epichlorohydrin (106-89-8), bisphenol A diglycidylether (1675–54–3), formaldehyde, methylenebis–phenylene diisocyanate, and triethanolamine (102–71–6). Substances occurring in the industry group personal services, cleaning, and hair dressing may be compared with substances found in an investigation based on registration of all cleaning agents used in Denmark in 1986 and still marketed in 1992.[24] For the allergens included in both the investigation on cleaning agents and in our investigation, the most often registered substances were the same—namely, the active ingredients in Kathon CG (5-chloro-2-methyl-3-isothiazolone and 2-methyl-3-isothiazolone), formaldehyde, and triethanolamine.

The model of extrapolation assumes that the groups of businesses are comparable in their use of chemicals. Homogeneity may not be the case, due to the size of the samples and the number of groups in the study being limited to $19 \times 4 = 76$. Although the use of chemicals may be well evaluated qualitatively, some indications of deficiencies in the quantitative aspects of use are present. Compared with statistics for the annual supply of pesticides,[25] our investigation tends to underestimate the use of specific pesticides (less than five times for half of the 15 pesticides included in our data, and several thousand times for two of the pesticides). The same tendency was seen in comparison with data on carcinogens registered by notifications from the manufacturers and importers (already mentioned). The estimation of annual use will, however, be further studied, and other models may be considered. For each industrial area further investigation may show different methods of extrapolation, and the model used may prove valid for selected areas only.

For chemicals with equally toxic properties and equal risk the choice of preventive measures depends on the distribution of the chemical in focus. When the number of exposure events is high, substitution may be the choice to prevent hazardous exposure, and when the number of exposure events is low or concentrated on few businesses it may be encapsulation or ventilation.

Two investigations have been used for setting priorities[2] and for development of a job exposure matrix.[26] These surveys on the use of chemical products were performed in the United States in 1972 and in 1980. The 1972 national occupational hazard survey included a sample of 4636 businesses. About 86 000 different trade named products were identified. Satisfactory component information was obtained for about 81% of the products.[1] In 1980 the national occupational exposure survey was started, which included 4490 businesses. More than 100 000 different trade named products were recorded. In June 1988 component information was obtained for about 50% of the products and the data were still regarded as provisional.[2] In our Danish survey component information was obtained for about 73% of the products when the data collection was closed after two years.

Surveys that rely only on data on weights of chemicals used may be criticised on the ground that many high weight chemicals are processed with little or no human exposure (enclosed processes). As a unique feature, our study collected data on the number of people who work with the substances, and it seems that chemicals that are used in large quantities and entail many exposure events should be given most attention, other things being equal.

Still we do not have information on the intensity or duration of the exposure. Different technologies may entail different levels of exposure—for example, manual assembly processes with solvent based glue can entail higher exposure levels for the individual worker than solvent based paints applied in industrial painting plants although the weights of chemicals used are larger in the painting industry. Therefore, the numbers of estimated exposure events cannot be taken

simply at face value when priorities are established. The combined information, however, on exposure events, weights, and other available knowledge (exposure, number of employees, preventive measures, etc) on the industry in question will reinforce the basis of the establishment of priorities.

This survey on the use of chemicals is the first nationwide investigation in Denmark to delineate the use of all chemicals (pure substances or components in chemical products). The investigation has provided a background knowledge of exposure to chemicals. In countries like Denmark (without a large production of (pure) chemical compounds or substances) this type of survey may be very useful as there is a need for knowledge on hidden occupational exposure to substances included in formulated products.

The study as a whole has been used in a project to review occupational hazards in general in Danish industry.[27] It will be a basis for measuring chemical substitution, development of chemical safety, and a reference data set for comparison in more specific investigations and follow up studies.

As information on work processes is included in the investigation, job exposure matrices based on the actual use of chemical products can be constructed from the collected data. Experiences from other studies will be used in future work and if possible the documentation and sample programmes available from the job exposure matrices based on the national occupational hazard survey will be adopted.[26]

Further surveys will monitor the development of chemical exposures in the working environment and the use of chemicals hazardous to health and to the external environment.

The design of our survey is planned to be used in another survey of a selected industry—namely, the printing industry. This study focuses on the use of carcinogens.

We acknowledge staff members in all parts of the working environment service involved in the data collection for our investigation.

Appendix: Industrial categories and ISIC codes included in each industry group

A special grouping of industrial areas was made for our chemical survey to cover groups with an expected comparable use of chemicals. The industry group numbers (the first two digits) refer to the Danish Sector Safety Council No, meaning that group 011, 012, 013, and 014 belong to the Sector Safety Council No 1.

INDUSTRY GROUP 011: MANUFACTURE OF BASIC METALS
ISIC 37XX Basic metal industries

INDUSTRY GROUP 012: MANUFACTURE OF FABRICATED METAL PRODUCTS
ISIC 381X Manufacture of fabricated metal products
ISIC 382X Manufacture of machinery and equipment
ISIC 41XX Electricity, gas, and steam
ISIC 42XX Water works and supply
ISIC 9512 Electrical repair shops
ISIC 9513 Repair of motor vehicles and motorcycles
ISIC 9514 Watch, clock, and jewellery repair
ISIC 9515 Repair and services of bicycles
ISIC 9519 Other repair not elsewhere classified (nec)

INDUSTRY GROUP 013: ELECTRICAL MACHINERY AND APPARATUS
ISIC 383X Manufacture of electrical machinery, apparatus, appliances, and supplies

INDUSTRY GROUP 014: MANUFACTURE OF TRANSPORT EQUIPMENT
ISIC 38YX (excluding boat building and repair) manufacture of transport equipment

INDUSTRY GROUP 021: PAINTERS AND CARPENTERS
ISIC 5014 Carpenters and joiners
ISIC 5015 Painters

INDUSTRY GROUP 022: CONSTRUCTION
ISIC 50XX (excluding carpenters, joiners, and painters) construction

INDUSTRY GROUP 031: PUBLISHING AND PRINTING
ISIC 3412 Manufacture of containers and boxes of paper and paperboard
ISIC 3419 (excluding manufacture of wall paper) manufacture of pulp, paper, and paper board articles
ISIC 342X Printing, publishing, and allied industries
ISIC 8325 Advertising services

INDUSTRY GROUP 041: WHOLESALE TRADE (SELECTED INDUSTRIES)
Specific Danish subdivision of ISIC 6116, 6118, and 6119:
- Grain, feeding stuffs, and fertilisers (subdivision of ISIC 6116)
- Seeds and bulbs (subdivision of ISIC 6116)
- Timber, and building materials (subdivision of ISIC 6116)
- Machinery and equipment (subdivision of ISIC 6118)
- Motor cars, motorcycles and parts, petrol, solid and liquid fuels, lubricants (subdivision of ISIC 6119)

INDUSTRY GROUP 051: MANUFACTURE OF TEXTILES AND LEATHER
ISIC 32XX Textile, wearing apparel, and leather industries
ISIC 9511 Repair of footwear and leather goods

INDUSTRY GROUP 052: MANUFACTURE OF WOOD AND FURNITURE
ISIC 33XX (excluding upholstered furniture) manufacture of wood and wood products
ISIC 3411 Manufacture of pulp, paper, and paperboard
ISIC 3410 (part) Manufacture of wall paper

INDUSTRY GROUP 053: MANUFACTURE OF CHEMICALS
ISIC 3511 Manufacture of basic industrial chemicals except fertilisers
ISIC 3512 Manufacture of fertilisers and pesticides
ISIC 3522 Manufacture of drugs and medicines
ISIC 3523 Manufacture of soaps and cosmetics
ISIC 3529 Manufacture of chemicals, nec
ISIC 355X Manufacture of rubber products

INDUSTRY GROUP 054: MANUFACTURE OF PAINTS, PETROLEUM, AND BITUMEN PRODUCTS
ISIC 3521 Manufacture of paints, varnishes, and lacquers
ISIC 3530 Petroleum refineries
ISIC 354X Manufacture of miscellaneous products of petroleum and coal

INDUSTRY GROUP 055: MANUFACTURE OF NON-METALLIC MINERAL PRODUCTS
ISIC 36XX Manufacture of non-metallic mineral products except petroleum and coal

INDUSTRY GROUP 056: MANUFACTURE OF PRECISION AND OPTICAL INSTRUMENTS
ISIC 3851 Manufacture of professional and scientific, and measuring and controlling equipment, nec (excluding orthopaedic and prosthetic appliances)

ISIC 3852 Manufacture of photographic and optical goods
ISIC 39XX Other manufacturing industries
ISIC 62XX (part of wholesale trade, excluding photographic equipment) retail trade of clocks, jewellery and pewter, and optical goods

INDUSTRY GROUP 057: MANUFACTURE OF PLASTIC AND BOAT BUILDING AND REPAIR
ISIC 3513 Manufacture of synthetic resins, plastic materials, and man made fibres except glass
ISIC 3560 Manufacture of plastic products, nec
ISIC 3841 (part) Boat building and repair

INDUSTRY GROUP 081: PERSONAL SERVICES, CLEANING AND HAIR DRESSING
ISIC 9202 (part) House and window cleaning
ISIC 9520 Laundries, laundry services, and cleaning and dyeing plants
ISIC 9591 Barber and beauty shops

INDUSTRY GROUP 082: SEWAGE AND REFUSE DISPOSAL
ISIC 9200 (part) Garbage and sewage disposal

INDUSTRY GROUP 101: AGRICULTURE, HUNTING, AND FORESTRY
ISIC 11XX Agriculture and hunting
ISIC 12XX Forestry and logging

INDUSTRY GROUP 111: HEALTH SERVICES AND PHARMACIES
ISIC 3851 (part) Manufacture of orthopaedic and prosthetic appliances
ISIC 62XX (part) Pharmacies
ISIC 9331 Medical, dental, and other health services
ISIC 9332 Veterinary services

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